(b) The frequency of the input force should equal the resonant frequency of the swing.

Applying Inquiry Skills

3. (a) If you gently rub the edge of an empty wine glass, the glass will ring with its resonant frequency. Fill up the glass with water, recording its resonant frequency at each level.
   (b) Prediction: the higher the water level, the lower the resonant frequency.
   (c) The experimental results should give qualitative proof of the prediction.

Section 6.7 Questions

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Understanding Concepts

1. At this stage, encourage students to think of resonance in mechanical systems. Resonance of sound in musical instruments will be discussed in Chapter 8. Some examples include:
   - car tires that are not properly balanced will vibrate with a fairly large amplitude at certain speeds. The amplitude of vibration can be reduced by increasing or decreasing the speed.
   - a pot partially filled with water vibrates while being heated on a stove.
   - swinging the arms with a frequency that corresponds to the step frequency.
   - objects on or near a loud stereo system or near a car playing loud music vibrate with a noticeable amplitude.
   - water pipes that resonant when a tap is turned on.
2. The car can be moved out of the snow by rocking it back and forth in the rut. By carefully timing the changing of gears from forward to reverse, the car can be made to rock in resonance with the gear changes. In the same way, pushing a child on a swing increases the amplitude of the swing, provided the push occurs exactly at either end of each swing and with the same natural frequency.

Making Connections

3. In addition to strengthening the building structure with cross supports, it is now common practice to put the base of the building on a moveable support. The moveable support partially absorbs the energy so that it is not all transmitted to the building. Commonly used are giant spring platforms or thick rubber pads under the supporting columns of the building.

6.8 STANDING WAVES — A SPECIAL CASE OF INTERFERENCE IN A ONE-DIMENSIONAL MEDIUM

Activity 6.8.1 Standing Waves in a One-Dimensional Medium

(Page 226)

Analysis

(a), (b) When two series of waves with equal frequencies and amplitudes are generated from opposite ends of a spring the resultant displacement appears as shown in **Figure 1**. Complete destructive interference occurs only when the amplitude and frequency of both waves are the same.

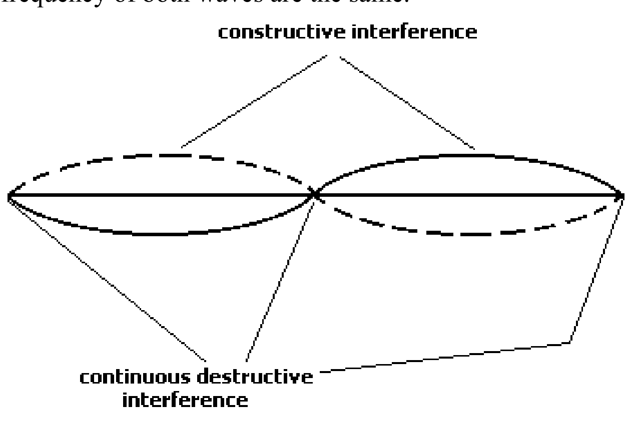

Figure 1
Original Frequency

At higher and lower frequencies, the resultant displacement of the spring is shown in **Figure 2** and **Figure 3** respectively.

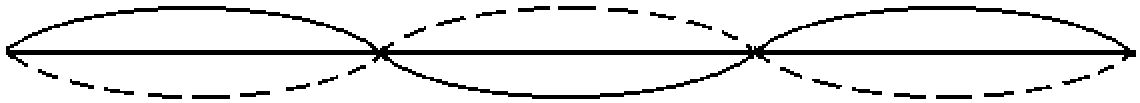

Figure 2
Higher Frequency than Original

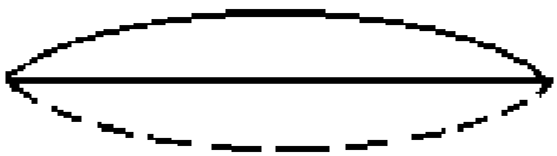

Figure 3
Lower Frequency than Original

(c) The markers placed on the floor at positions of fixed points (nodes) are located one half wavelength apart. Two “loops” in the standing wave constitute one wavelength (**Figure 4**).

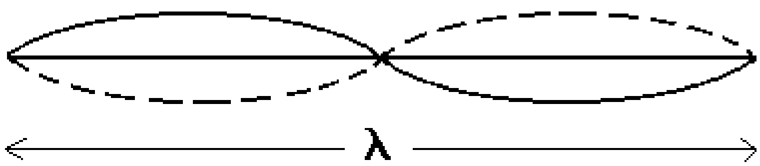

Figure 4
Standing Wave (one fixed end)

(d) When the spring is rigidly fixed at one end and waves are generated from the other, a standing wave pattern is created once again. See **Figure 5**. Destructive interference always occurs at the fixed end that is not free to vibrate.
(e) Standing waves are easier to produce from reflection off a fixed end than by generating waves from opposite ends of the medium because the two interfering waves which produce the standing wave pattern must be identical in frequency and amplitude, something not easily achieved by two people generating waves at opposite ends of a spring.
(f) It is easier to measure the wavelength of the wave from a standing wave pattern than from a travelling wave because there are fixed points on a standing wave which are known to be one half wavelength apart.
(g) The pattern produced by the electric vibrator situated at one end of the spring is a typical standing wave pattern. The distance separating five successive nodes is measured to be 40.0 cm, giving a wavelength of 20.0 cm. The frequency is determined to be 10.0 Hz. The speed of the wave is determined as follows:

$$v = f\lambda$$
$$= 10.0 \text{ Hz } (20.0 \text{ cm})$$
$$= 200 \text{ cm/s } (2.00 \text{ m/s})$$

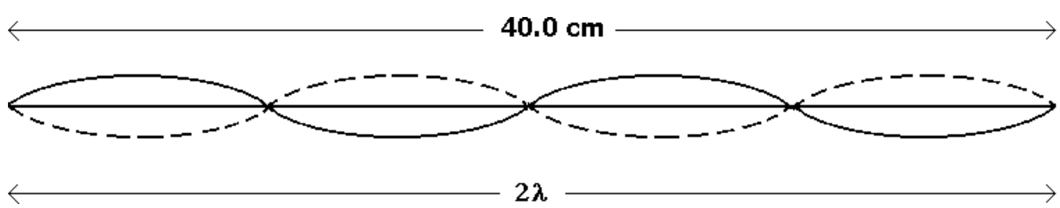

Figure 5

(h) If the speed of the wave were known, its frequency could be determined using the universal wave equation as above but solving for frequency. The wavelength can be determined by the separation of three successive nodes in the standing wave pattern.

PRACTICE

(Pages 229–230)

Understanding Concepts

1. The distance between successive nodes is $\frac{1}{2}\lambda$.

$$\frac{1}{2}\lambda = \frac{1}{2}(9.5 \text{ cm})$$
$$\lambda = 19 \text{ cm}$$

2. The distance between the second and fifth nodes represents three half wavelengths.

$$\frac{3}{2}\lambda = 59 \text{ cm}$$
$$\lambda = 39 \text{ cm}$$

$$v = f\lambda$$
$$= (25 \text{ Hz})(39 \text{ cm})$$
$$v = 975 \text{ cm/s or } 9.8 \times 10^2 \text{ cm/s}$$

3. (a) $\frac{1}{2}\lambda = 25.0 \text{ cm}$

$$\lambda = 50.0 \text{ cm}$$

(b) $v = f\lambda$

$$= (2.0 \times 10^2 \text{ Hz})(50 \text{ cm})$$
$$v = 1.0 \times 10^4 \text{ cm/s}$$

Applying Inquiry Skills

4. One possible procedure is to fix the rope at one end and vibrate the other end to send waves towards the fixed end. Then set up a standing wave with one antinode. Keeping the pattern fixed, determine the frequency by measuring the time for 20 complete cycles of the source (the hand moving up and down). Since the rope is vibrating with one antinode in the middle, the distance between the hand and the fixed end is $\frac{1}{2}\lambda$. If two antinodes are present, the wavelength will be decreased by half and the frequency will double. For three antinodes, the wavelength will be one-third and the frequency will triple.

Section 6.8 Questions

(Page 230)

Understanding Concepts

1. $\lambda = 4.0$ m (see **Figure 6**).

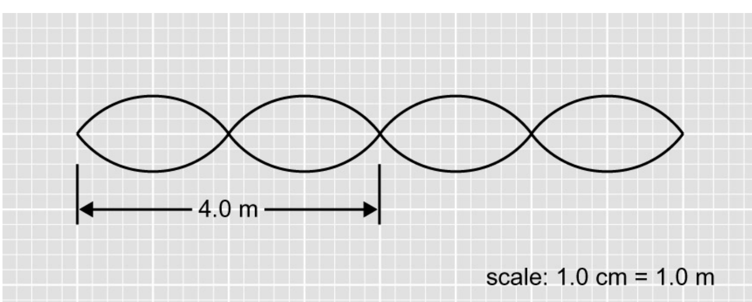

Figure 6

2. (a) one antinode

$$\frac{1}{2}\lambda = 4.0 \text{ m}$$
$$\lambda = 8.0 \text{ m}$$

$$f = \frac{v}{\lambda}$$
$$= \frac{3.2 \text{ m/s}}{8.0 \text{ m}}$$
$$f = 0.40 \text{ Hz}$$

(b) 2 antinodes = 1λ

$$\lambda = 4.0 \text{ m}$$

$$f = \frac{3.2 \text{ m/s}}{4.0 \text{ m}}$$
$$f = 0.80 \text{ Hz}$$

(c) 4 antinodes = 2λ

$\lambda = 2.0$ m

$f = \frac{3.2 \text{ m/s}}{2.0 \text{ m}}$

$f = 1.6$ Hz

3. 4 nodes = 2λ

$2\lambda = 82$ cm

$\lambda = 41$ cm or 0.41 m

$f = \frac{v}{\lambda}$

$= \frac{6.0 \text{ m/s}}{0.41 \text{ m}}$

$f = 15$ Hz

4. 1 antinode = $\frac{1}{2}\lambda$

$\frac{1}{2}\lambda = 2.0$ m

$\lambda = 4.0$ m

$f = \frac{v}{\lambda}$

$= \frac{2.8 \text{ m/s}}{4.0 \text{ m}}$

$f = 0.70$ Hz

2 antinodes = 1λ

$\lambda = 2.0$ m

$f = \frac{2.8 \text{ m/s}}{2.0 \text{ m}}$

$f = 1.4$ Hz

3 antinodes = 1.5λ

$1.5\lambda = 2.0$ m

$\lambda = 1.33$ m

$f = \frac{2.8 \text{ m/s}}{1.3 \text{ m}}$

$f = 2.1$ Hz

6.9 INTERFERENCE OF WAVES IN TWO DIMENSIONS

PRACTICE

(Page 232)

Understanding Concepts

1. The single straight line of constructive interference is located halfway between the two sources running perpendicular to the axis that joins them.
2. When the frequency of the sources is increased, the nodal lines become very close together and increase in number. This makes it more difficult to see the nodal lines.
3. If the distance between the sources is increased, there are more nodal lines because there is a larger area for the interference of the wave fronts to occur.

Applying Inquiry Skills

4.